Pamphlet No. 126.

Freight Locomotives for working across the Rocky Mountains.

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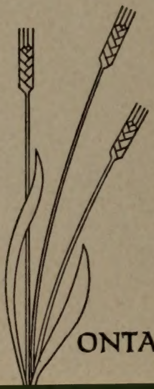

ONTARIO CANADA

The EDITH *and* LORNE PIERCE
COLLECTION *of* CANADIANA

Queen's University at Kingston

[PAMPHLET No. 126].

G.W.R. Mechanics' Institution.

Swindon Engineering Society

"FREIGHT LOCOMOTIVES FOR WORKING ACROSS THE ROCKY MOUNTAINS"

BY

MR. GEORGE BULKELEY, A.M.I. Mech. E.
(LIFE MEMBER).

EXCERPT OF TRANSACTIONS, 1920-21.

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[No. 126]

G.W.R. Mechanics' Institute.

SWINDON ENGINEERING SOCIETY.

TRANSACTIONS, 1920-1921.

ORDINARY MEETING.—FEBRUARY 8TH, 1921.

Chairman—Mr. F. W. HAWKSWORTH.

"FREIGHT LOCOMOTIVES FOR WORKING ACROSS THE ROCKY MOUNTAINS."

BY

Mr. GEORGE BULKELEY, A.M.I.Mech.E. (Life Member).

THE provision of suitable locomotives to meet severe and difficult working conditions is always the most fascinating and romantic section of locomotive engineering; I have thought that a brief description of how the Canadian Pacific Railway have met the ever-increasing traffic demands of the last 10 years for adequate power in their Rocky Mountain Section, together with a short description of that Section, would be of interest to the Members of this Society.

I am speaking as a former member of the C.P.R Locomotive Staff, and also as one who has lived for some years on the Western side of the Rocky Mountains, so I may as well admit at the outset that I am an whole-hearted enthusiast on the subject of this paper.

The fact that I am able to illustrate, as well as describe, some of the locomotives constructed by the Canadian Pacific Railway, is due to the kindness of Sir George Maclaren Brown, that Company's European General Manager; Mr W. H. Winterrowd, their Chief Mechanical Engineer; also the Canadian Railway Club of Montreal, to whom my thanks are due for the original photographs and drawings.

First, just a word as to Canada as a whole and as to the extent of the C.P. Railway. Canada is nearly as large as Europe, and has a larger area than the United States. The relative populations are as follows:—

Great Britain	471	persons per square mile.
United States	25	,, ,, ,,
Canada	2	,, ,, ,,

There is plenty of room in Canada, and 500,000 settlers on the land are now being invited to go there.

Now as to the C.P.R.:—

Its length of *direct main line* from the Atlantic to Pacific	3,740 miles.
Total track mileage	18,250 ,,
Telegraph wire mileage	100,000 ,,

The City of Winnipeg is about half-way across; and between there and the foot hills of the Rocky Mountains lie about 1,000 miles of prairie land, gently rising from an altitude of 750 feet at Winnipeg to 3,550 feet at Calgary. It is a sight never to be forgotten to pass over this prairie section when the wheat is ripe for reaping and the westering sun gleams tawny gold across millions of acres of ripe grain.

From the East to the Rocky Mountains, the standard passenger engine is of the Pacific, 4-6-2 type, and Fig. 1 shews the latest class of this locomotive. It is claimed that they are the largest and finest 4-6-2 Passenger locomotives built up to the present date, and I think you will agree that they look the part. They are two cylinder machines, having cylinders 25in. in diameter by 30in. stroke. Driving wheels are 6ft. 3in. in diameter. Boiler pressure 200 lbs. per square inch, superheated. The cylinder tractive effort at 85 per cent. boiler pressure is 42,600 lbs. Adhesion factor 4.25. Total weight 133 tons without tender.

The new standard C.P.R. locomotive cab is of considerable interest. As you know, the weather is sometimes as much as 50°—60° below zero, and an engine crew therefore need very complete protection in winter, especially when the lonely nature of some of the long sections is taken into consideration. On the other hand, the Canadian summer is generally very hot, and enginemen must have as open a cab as possible.

The cab is termed a "vestibule" one. It is completely enclosed on all sides, and is entered through side doors; in the winter therefore it is a snug roomy compartment. In the summer very thorough ventilation is secured through the large side windows and the door openings. We will climb up into one of these comfortable cabs and take a trip over the Rocky Mountain Section of the Railway alongside the engineman, who, it being mild weather, is seated beside the large open side windows, with the throttle convenient to his left hand and on his right the air-brake valve.

The C.P.R. gradient section across the Rocky Mountains is as follows: From Calgary (altitude 3,500 feet) the grade rises for 130 miles to 5,321 feet altitude; falls in 50 miles to 2,500 feet; rises in 20 miles to 4,300 feet; falls in 45 miles to 1,500 feet; and from

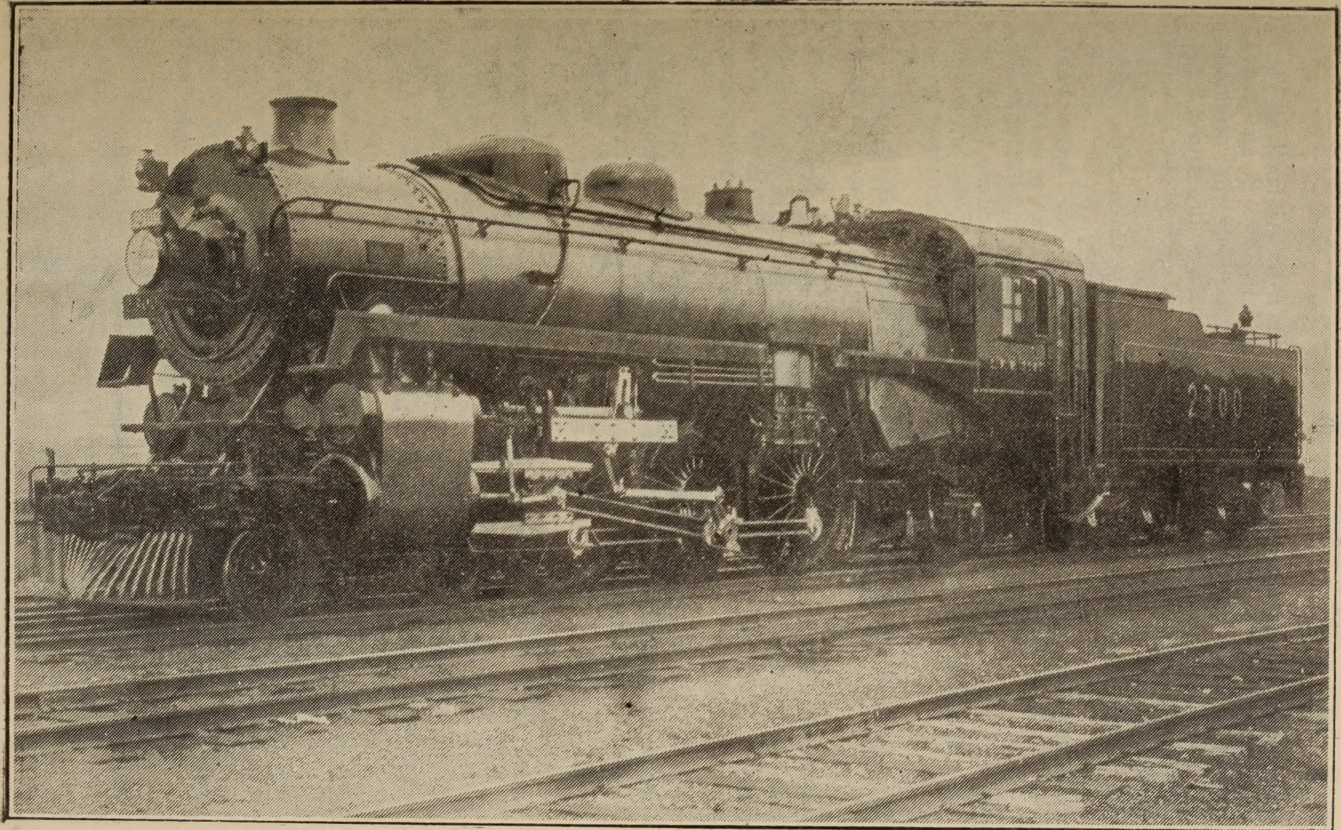
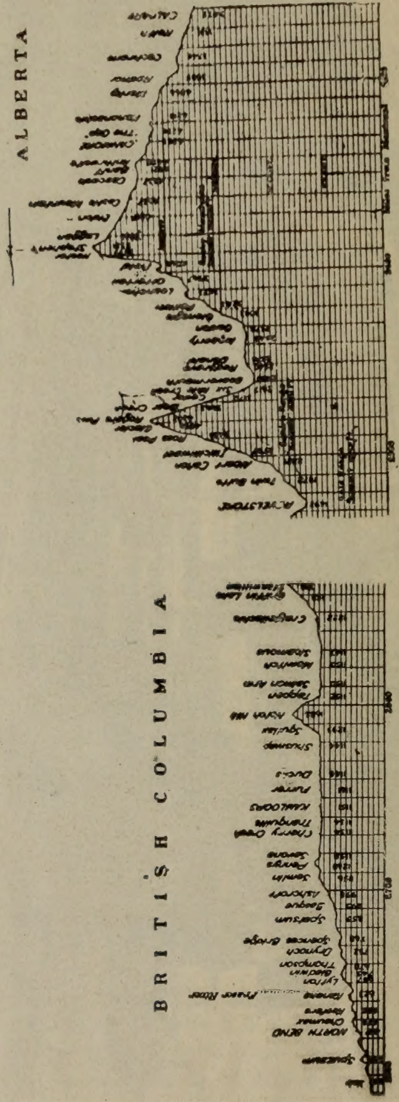


Fig. 1.

thence undulates for about 100 miles down to sea level at Vancouver. The steepest climb is a rise of 1,133 feet in about five miles, as the crow flies. Parts of the grade here were originally no less than 4.5 per cent., but have now been reduced to 2.2 per cent. by the provision of two spiral tunnels, each about 1½ miles in length.



PROFILE OF CANADIAN PACIFIC RAILWAY FROM CALGARY TO YALE

The Rockies are entered from the East at a point known as "the Gap." The romance of the long search for a practical southerly railway entrance to the Rockies by the pioneer engineers is known to all, and is an epic in the annals of civil engineering; indeed these terrific mountains appear impassible as the train first approaches them, and you realise at once that the locomotives which work across them have got to be *some pullers*. As the rail tracks lead on, enormous masses of mountains tower on either hand; some black and serrated; others white with eternal snows, or having the brilliant shining green of glaciers on their shoulders. And ever the rails lead onwards—creeping round corners of mountain bastions; along precipice edges; over valleys of profound depths; traversing spider bridges over roaring torrents, or burrowing through spiral grade-reducing tunnels.

Fig. 2 shews a general type of 2-8-0 locomotive working over the C.P.R. in 1908.

The cylinders are 21in. diameter by 28in. stroke. Diameter of driving wheels 4ft. 10in. Boiler pressure 200 lbs. per square inch. Tractive effort 36,200 lbs. Adhesion factor 4.65. Total weight of engine 185,000 lbs.

In fact very similarly powered engines to the Great Western 2-8-0 machines. These C.P.R. engines were fitted with superheaters, as has every one of their locomotives been since the earliest years of this century.

(It will, I think, interest Great Western men to hear that a somewhat similar experiment to the new G.W.R. 2-8-0 mixed traffic engine, with 5ft. 8in. wheels, was made by the C.P.R. in 1909. A 2-8-0 engine being then built, having 5ft. 3in. wheels, cylinders 24in. by 32in., and a boiler pressure of 200 lbs. The tractive effort of this engine was 44,700 lbs., and adhesion factor 4.357.)

In 1909 it became necessary to increase the tractive effort of locomotives working over the Rocky Mountains, and Mr. H. H. Vaughan, then Superintendent of Motive Power, decided to ascertain by direct experiment whether a Malet-Articulated Compound, built to the limits of overall length and weight then allowable on the C.P.R., would be more advantageous for this service than 2-cylinder simple locomotives.

The usual type of Malet-Articulated engine then being built in the United States was of the 2-6-6-2 type; the rear engine being the high pressure one, and the cylinders of the front low pressure engine being located ahead of the engine, the total wheel base of engine and tender being about 77ft. 0in.

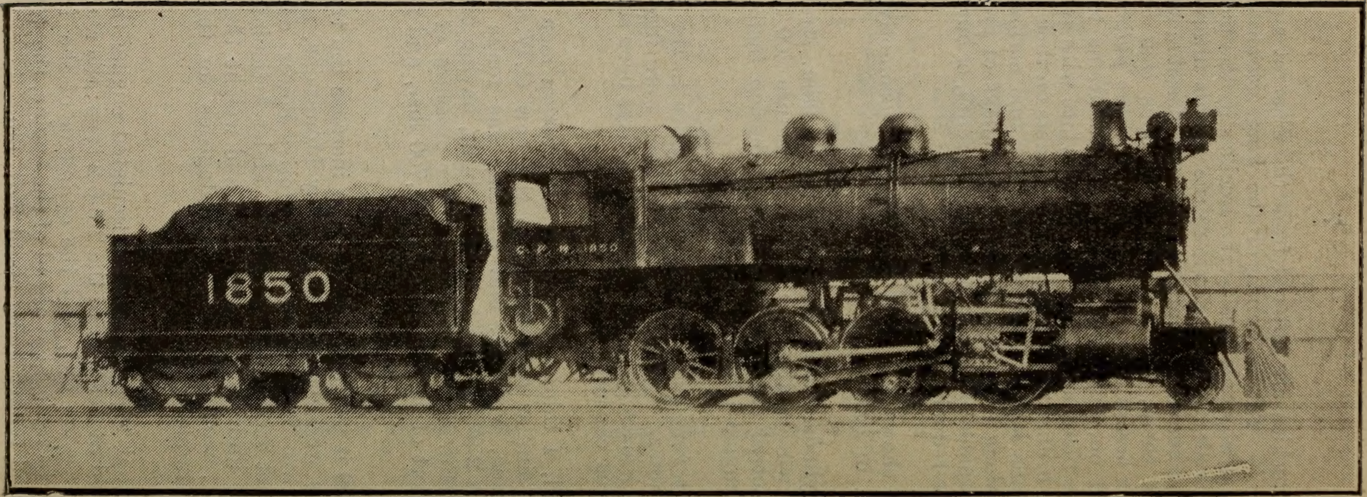


Fig. 2.

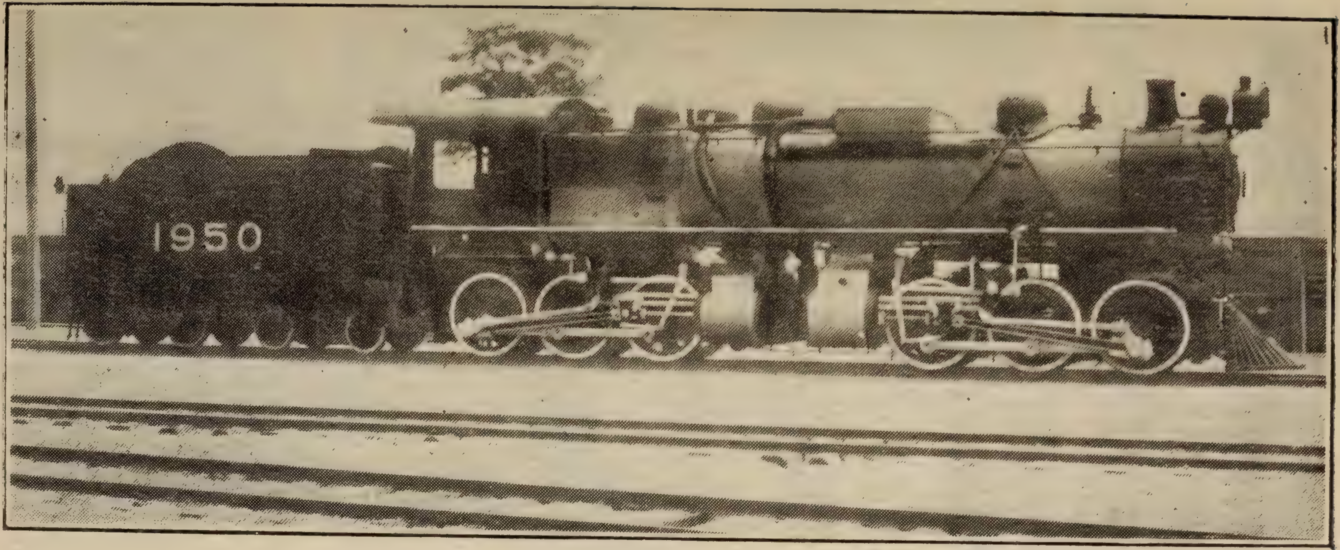


Fig. 3.

Such an arrangement was at that date impracticable in the case of the C.P.R., for two main reasons:—

(1) It would be too heavy for the bridges.
(2) It would be too long to turn on a 70ft. 0in. turntable.

Mr. Vaughan therefore decided to design a Malet engine which would both meet C.P.R. conditions as to weight and also turn on a 70ft. 0in. table.

Fig. 3 shows how this was accomplished, the resulting engine weighing 117 tons only. I was in the C.P.R. Locomotive Drawing Office at that time, and was one of the draughtsmen who were turned on to making the drawings for this engine to Mr. Vaughan's schemes. I think some details of its novel and ingenious construction may be of considerable interest, and I have permission to shew these to you to-night.

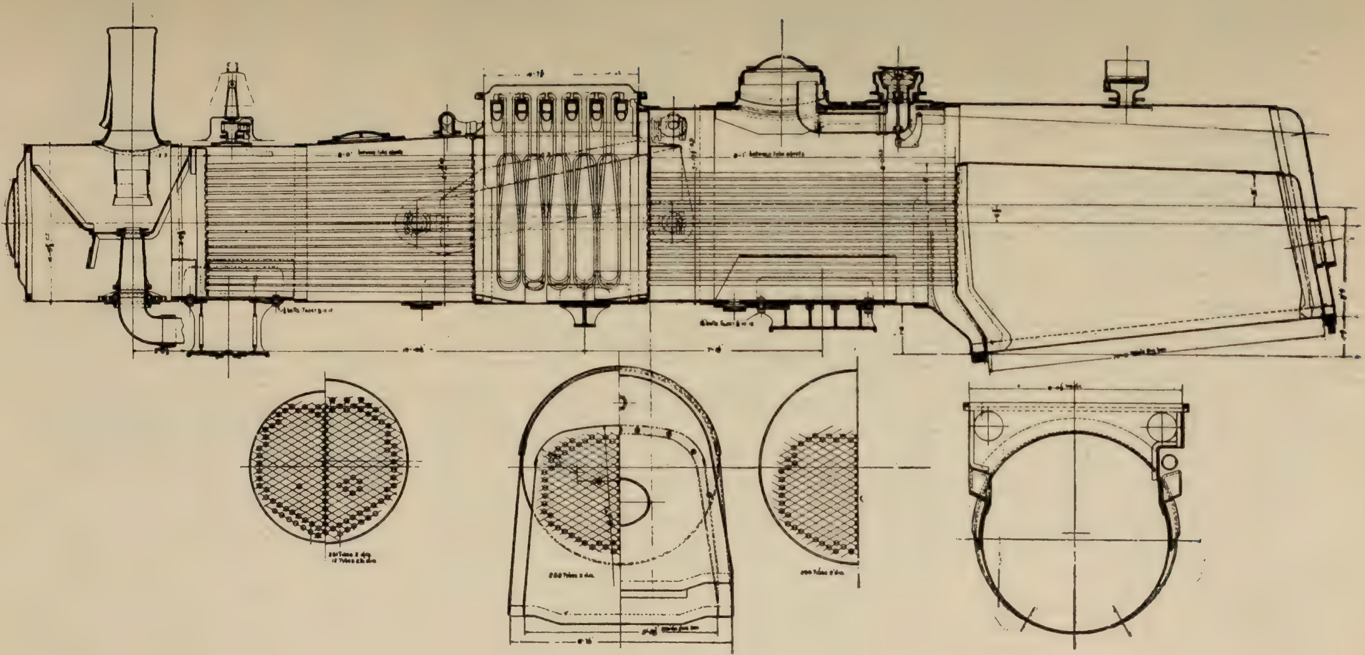
Fig 4 shows the boiler of the Malet Engine. This, as can be seen, was of a very unusual type. It had three sections:—

(1) Boiler proper.
(2) Superheater chamber.
(3) Feed-water heater.

The injectors fed into the front, or feed-water heater section, which, being of small diameter, was always full of water. It will be of special interest to Great Western men to know that the feed water was fed in through check valves located on the *top* of the barrel. The feed-water section of the boiler had a heating surface of 1,250 sq. feet.

The superheater had 69 elements each consisting of double loops of 1¼in. steel tubing. These superheater pipes were secured to the headers by union nuts, and so were readily removable for repairs. Also the complete superheater could be easily hoisted out of its chamber through a flanged steel door which closed the top of the latter. It is interesting to note that no cinders were ever found to collect in these chambers.

The Boiler proper appears of unusually short length: nevertheless these engines were remarkably good steamers under all conditions of working. The Firebox is large and the Grate Area 58 square feet. A special point was made of having the internal and external radii of the firebox very large, and the absence of broken stays was specially noticeable with these boilers. The total heating surface of this section of the boiler was 1,555 square feet. The working pressure was 200 lbs. per sq. inch; the highest superheat recorded being 153 degrees in the high pressure steamchests. Two outside 12in. pipes connect the feed water section and the boiler proper—one at the side and one on the top.



Boiler, Attachments and Superheater.

Fig. 4.

The throttle valve was located on top of the boiler as shown. It was a casting having two outside 5in. steam delivery connections. The joint with the boiler was made by a brass ball ring having a 12¾in. inside opening to boiler. Steam was taken from a small steam dome; from which the drypipe led to the throttle valve.

The two 5in. outside steam pipes from throttle led:

(*a*) *As first built:* direct to H.P. cylinders.
(*b*) *As finally decided:* to superheater and thence to H.P. cylinders.

All of this piping is, of course, high pressure; but presents no complications; as, so far, the engine is rigid and there is no pipe movement.

Fig. 5 shews the cylinder arrangement. The H.P. Cylinders had inside admission valves, exhausting (partially through the valve as a pipe) into a common header, bolted across the front ends of the H.P. cylinders, as shewn, and from which a 7in. pipe led (as the engine was *first built*,) to the superheater. This latter thus acted as a re-heater for the H.P. exhaust which was by this means reheated to a temperature of about 440 degrees; the average pressure being 75 lbs. per sq. inch, (120 deg. superheat) in the L.P. Steam chests.

After a series of experiments the superheater was finally connected up between the boiler steam and the H.P. cylinders, and the H.P. exhaust steam led direct to the L.P. cylinders.

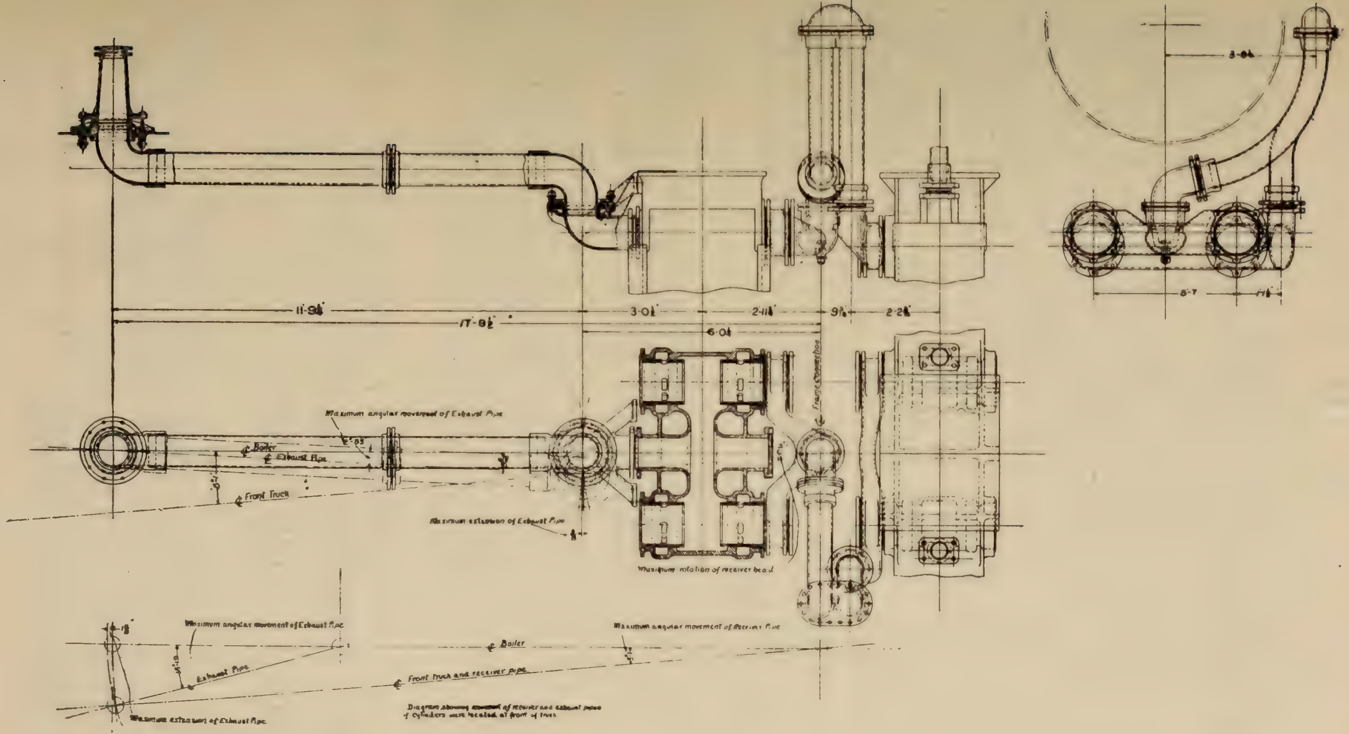
It will be realised that, in either of the above arrangements there had to be an L.P. pipe movement, owing to the articulation of the engine, and this was accomplished in the simplest possible manner by making this joint a plain swivelling one, immediately above the articulated pin. This joint was packed with alternate cast-iron and white metal rings, *and was the only packed joint in the steam piping.*

A second cross-header was bolted across the rear ends of the L.P. cylinders; which latter had external admission piston valves (which also acted as steam pipes for the front ends of the L.P. cylinders).

It will have been noted that, so far, the steam piping has been accomplished with the introduction of a single joint only, and that of the simplest possible description.

Now as to the L.P. exhaust piping:

The L.P. exhaust pipe leads from the cylinder casting along the centre line of the engine and curves up under and into the smoke-box, as shewn in the diagram. Both ends of this pipe have ballring joints, and both ends have a small rotary movement: but


11-9¾
17-8½
3-0½
2-11¼
9⅞
2-2⅝
6-0¼
8-7
3-0¼
Frame Connection
Maximum angular movement of Exhaust Pipe
℄ Boiler
℄ Exhaust Pipe
℄ Front Truck
Maximum extension of Exhaust Pipe
Maximum rotation of receiver head
Maximum angular movement of Exhaust Pipe
Exhaust Pipe
Maximum extension of Exhaust Pipe
℄ Boiler
℄ Front truck and receiver pipe
Maximum angular movement of Receiver Pipe
Diagram showing movement of receiver and exhaust pipes
if cylinders were located at front of truck

Steam. Exhaust and Receiver Pipes
Dotted lines show positions on 20° curve

Fig. 5.

as the angular movement is only 2 minutes 30 seconds on a 20 degree curve, the pipe extension is only ⅜in., which is easily taken up by the sliding of the pipe flanges across the flat faces of the ball rings. These flanges are held to their seats on the ball-rings by ten helical springs each producing a pressure of 200 pounds. The extension due to the front engine movement being thus provided for, there is no need for any packed expansion joint. The dotted lines shew the movements of the pipe on a 20 degree curve; while the diagram at the bottom shews the greatly increased pipe movement which would have occurred had the L.P. cylinders been at the front of the engine. Comparing the two alternative piping arrangements, it will be observed that, with the L.P. cylinders located at the front of the engine, the angular movement of the exhaust pipe would have been 15 degrees 19 minutes on the 20 degree curve, and the L.P. exhaust pipe extension 1⅝in., which would have necessitated the use of two universal ball joints with packing, and also a packed expansion joint to take up the sliding movement.

The receiver pipe movement would have been much the same; and this pipe is usually given flexibility by one packed ball joint and one packed expansion joint when the L.P. cylinders are at the front of the engine.

From the above, and the diagram, it will be noted that, had the L.P. cylinders been placed in front of the engine, and following the usual pipe arrangements, *five* packed joints would have had to be used as against the *one* required on the engine under review.

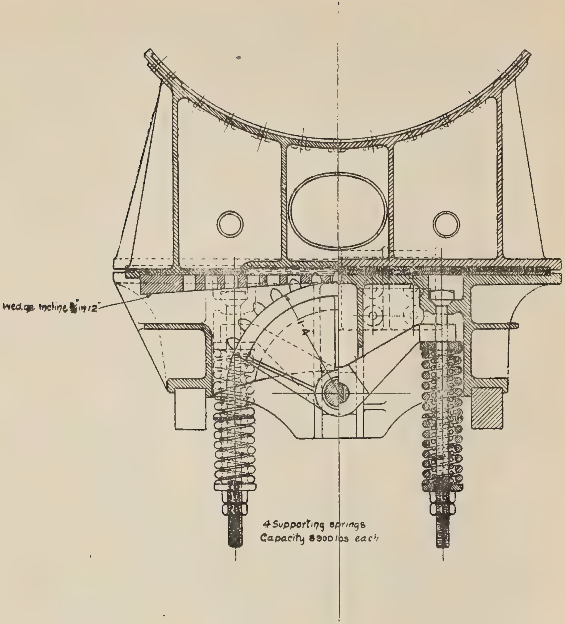
Regarding the Walschaert valve gear, there is nothing particular to mention, except that the L.P. radius bar lifting link is made very long to minimise the altered L.P. valve travel brought about when the engine is curving. The maximum boiler swing is 9in. off the centre-line of the front engine and tends to shorten the L.P. valve travel when that engine is in forward gear; and vice versa.

Provision was also made for varying the cut-off in the L.P. engine without altering that of the H.P. engine (this was done by having a slot in the H.P. radius bar lifting arm).

Fig. 6 shews the arrangement devised to take care of the engine when curving.

As previously explained, one of the main objects in the design of this engine was to keep it of short overall length and that therefore the customary leading 2-wheel truck was omitted. It was felt that the L.P. engine itself, swinging about its rear articulated pin, should adequately provide all the guiding necessary.

The construction and action of the centring and guiding device illustrated were as follows:—



Boiler Bearing and Guiding Attachment.

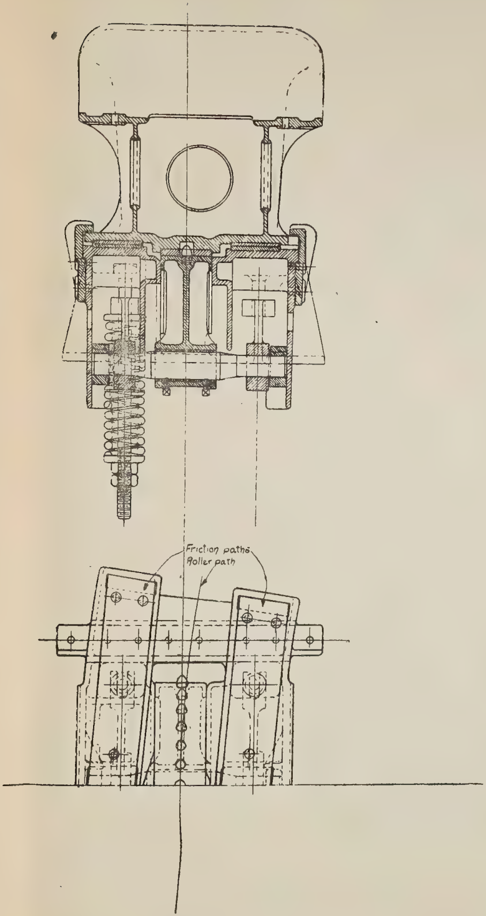


Fig. 6.

The boiler, which offers the principal resistance to curving, was supported on the front truck (which swings laterally under it) partly by friction plates, and partly by a spring suspended roller.

Referring to the drawing. There are two main castings; one mounted on the frames and the other rigidly supported by the boiler. The weight of the boiler at this point was 40,000 lbs. and one-half of the weight was carried on the two radially-curved friction plates shewn. The total area of these plates was 834 sq. inches, and they were lubricated by having oil grooves cut in them.

The resistance due to friction alone as the engine starts to curve is 1,600 lbs.

In the space between the two friction plates is the roller path, which consisted of two inclined planes rigidly secured to the boiler casting. These wedges have their thin ends terminating about 2in. on either side of the engine centre-line, and their inclination is ¾in. in 12in.

The roller, across which these inclined planes moved as the engine curves (either to one or other side), is carried by two equalizing double-arms, as can be seen in the drawing: these arms being in turn supported by the long spiral springs bearing on the frame-carried casting.

Any movement of the front truck sideways, causes the inclined plane on that side to force the roller downwards against the resistance of the spiral springs; and this produces a force which pulls the boiler round the curve along with the front truck, and relieves the leading flanges of the rear truck from the excessive pressure which would otherwise be set up: the arrangement also provides the necessary centring action when the engine again reaches the straight.

This rolling resistance commences at the bottom of the wedges, or 2in. from the centre-line of the engine on either side, rises at once to 1250 lbs., and increases to a maximum of 1965 lbs. at the maximum point of sideways-movement of the front truck.

The frictional resistance slightly decreases, as the weight on the friction plates is gradually lessened by being transferred to the roller; while the resistance offered by the latter could be changed very readily, if desired, by altering the inclination of the wedges or by screwing up the roller supporting springs' bottom nuts.

This has the effect of increasing the weight on the roller and decreasing the weight on the friction plates: or vice versa.

Various tests were made on the first of this series of engines. The following are some of the most interesting results:—

The flange wear after 4,000 miles running was 3-64in. on the leading wheels and 1-32in. on the others. This was satisfactory. The Malet locomotive curved easier and did less damage to the rails than the ordinary 2-8-0 engines. The many curvatures which have to be traversed in regular working are from 18 to 10 degrees.

The cylinders of the first engine were fitted with removeable bushes, and the following results were obtained from 6 groups of tests:—

Indicator cards representative of the important experimental changes made in the engine during tests are shewn in Fig. 7.

Test Group No. 1:—The size of the cylinders in the first instance were H.P. 22in. and L.P. 32½in. by 26in. stroke, or a ratio of 2.18.

With these cylinders, and the H.P. exhaust passing through the reheater, it was found that the L.P. cylinders were developing considerably greater horsepower than the H.P. ones: the former doing 42 per cent. of the work and the latter 58 per cent. This was probably partially due to the increased volume of steam going to the L.P. cylinders, owing to its being reheated and consequently expanded en route, and causing excessive back pressure on the H.P. pistons: this is indicated by the H.P. back pressure being higher than the L.P. initial pressure, as shewn on the diagram. The tractive effort averaged 45,500 lbs.

Test Group No. 4:—The diameter of the L.P. cylinder was increased to 34in., or a ratio of 2.38 The reheater was left connected to the H.P. exhaust. With this alteration in L.P. cylinder diameter, the work was much better divided between the two engines—48 per cent. being done by the H.P. engine and 52 per cent. by the L.P. one. The tractive effort then averaged 46,500 lbs.

Test Group No. 5:—The reheating of the H.P. exhaust was then discontinued and the boiler steam superheated before passing to the H.P. cylinders; The cylinder ratio remaining at 2.38 The division of work between the two engines remained much as in the last test, but a tractive effort of 52,000 was recorded.

Test Group No. 6:—The previous tests shewed that with a cylinder ratio of 2.38 the engines were very well balanced in power output. It was, however, desired to get the *most power possible* out of the engine, and, the factor of adhesion still being high, it was decided to increase the size of the H.P. cylinders. These were therefore increased from 22in. to 23½in. in diameter; but it

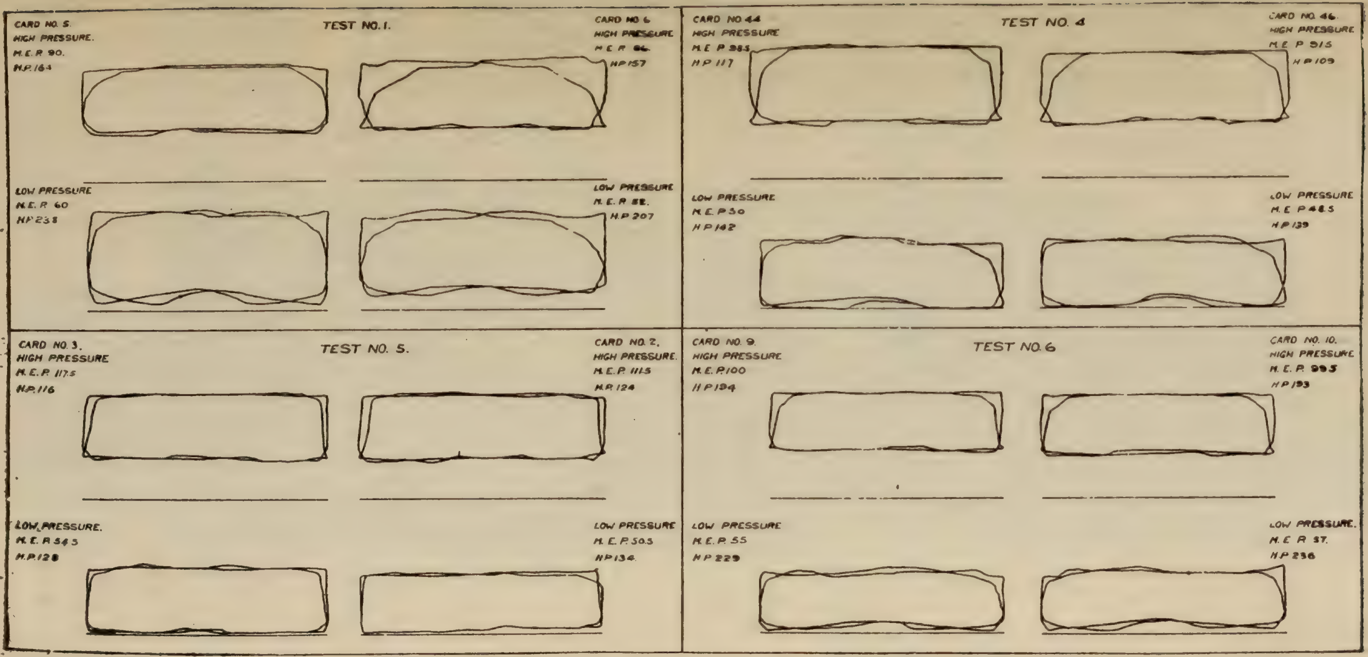

TEST NO. 1.
CARD NO. 5.
HIGH PRESSURE.
M.E.R 90.
H.P. 164
CARD NO 6
HIGH PRESSURE
M E R 86.
H.P 157
LOW PRESSURE
M.E.R 60
H.P 238
LOW PRESSURE
M.E.R 88.
H.P 207
TEST NO. 4
CARD NO 44
HIGH PRESSURE
M.E P 98.5
H P 117
CARD NO. 46.
HIGH PRESSURE
M.E P 91.5
H P 109
LOW PRESSURE
M.E.P 50
H P 142
LOW PRESSURE
M.E P 48.5
H P 139
TEST NO. 5.
CARD NO. 3.
HIGH PRESSURE
M.E.P. 117.5
H.P. 116
CARD NO. 2.
HIGH PRESSURE.
M.E.P. 111.5
H.P. 124
LOW PRESSURE.
M.E.P 54.5
H.P. 128
LOW PRESSURE
M.E.P. 50.5
H.P 134.
TEST NO. 6
CARD NO. 9.
HIGH PRESSURE
M.E.P. 100
H P 194
CARD NO. 10.
HIGH PRESSURE
M.E.P. 99.5
H P 193
LOW PRESSURE
M.E.P. 55
H P 229
LOW PRESSURE.
M.E P 57.
H.P 236

Fig. 7.

was not possible to bore out the L.P. cylinders any larger. The cylinder ratio now therefore became 2.18; the superheater being left connected between the boiler and H.P. cylinders. The division of power between the H.P. and L.P. engines was now 45 per cent. and 55 per cent. respectively, and a tractive effort of approximately 54,000 lbs. was realised with a 1140 ton train on a gradient of 1 in 65.

The locomotive was then put into "pusher" service in the Rocky Mountain section of the railway.

The full summer rating over the section of the Rocky Mountains worked by these Malets was, with the ordinary 2-8-0 engines, 424 tons. The maximum grade being 1 in 45. The Malets were designed to take 660 tons over this section, and in practice it was found that they could take 700 tons comfortably. the maximum tractive effort actually exerted by them in practice being 57,400 lbs.

The coal used is mined in the Rocky mountains and is very dusty. The Malets steamed well with it, however, the blast pipe orifice being 4¾in. Owing to the long length of the exhaust pipe the exhaust was very mild.

Six of these Malets were constructed; and they handled the traffic over the section until 1916.

The maintenance of these double engines was, however, high *for their power*: also the necessity for having considerable lengths of exposed steam piping in a Malet locomotive proved an undesirable feature in the extremely cold weather experienced in the Rocky Mountains.

In 1917, therefore, when the demand for increased power on the Rocky Mountain Section again became insistent, 35 engines were constructed of the 2-10-0 type as shewn by Fig. 8.

These engines have 2 simple cylinders, 24in. diameter by 32in. stroke. The boiler pressure is 200 lbs. per sq. inch, and the steam superheated. The driving wheel diameter is 4ft. 10ins. and the tractive effort 54,100. Nearly the same tractive effort as the Malets was therefore attained in these engines, which weigh 112 tons.

Last year it was decided to see whether still greater power could not be satisfactorily obtained from a suitable *unarticulated* engine, and the present Chief Mechanical Engineer of the Com-

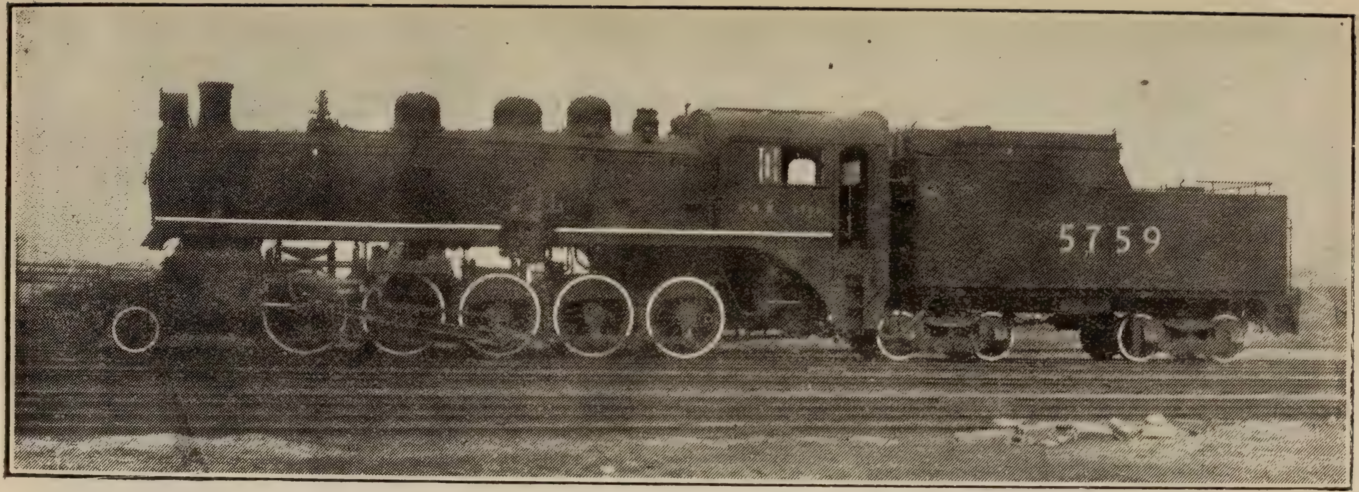


Fig. 8.

pany, Mr. W. H. Winterrowd, has designed and constructed at the Company's Shops at Montreal, 15 Santa Fe, or 2-10-2, locomotives as illustrated in Fig. 9. *These are the most powerful engines which have been put into Canadian Railway service up to date and they weigh 158 tons.*

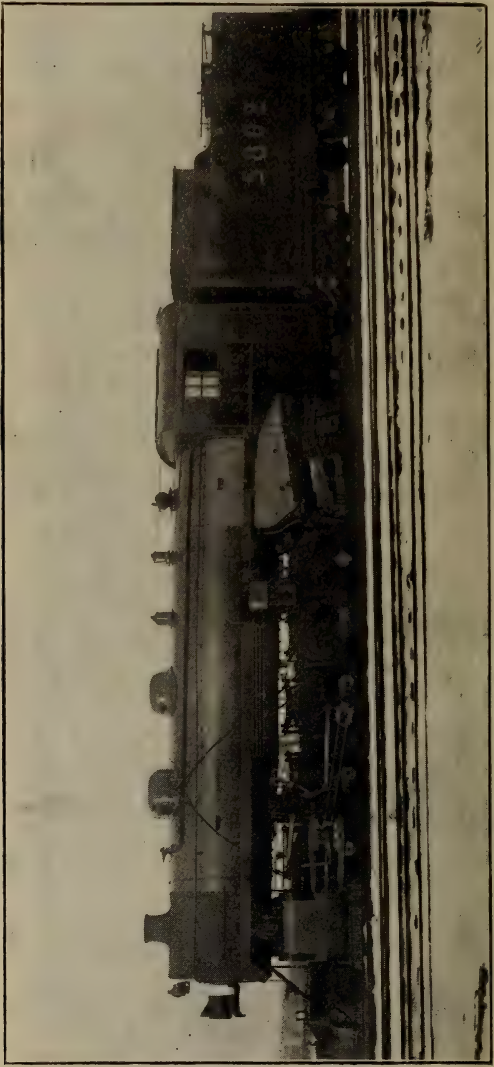


Fig. 9.

They have 2 simple cylinders of 26½in. diameter and 32in. stroke. The boiler pressure is 200 lbs. to the sq. inch, and the steam superheated. The driving wheel diameter is 4ft. 10in. Their tractive effort at 85 per cent boiler pressure is 65,870 lbs., and the adhesion factor 4.18.

Up to date these fine locomotives are doing all that can be put on to them by the operating Department over the Rocky Mountain Section of the Railway.

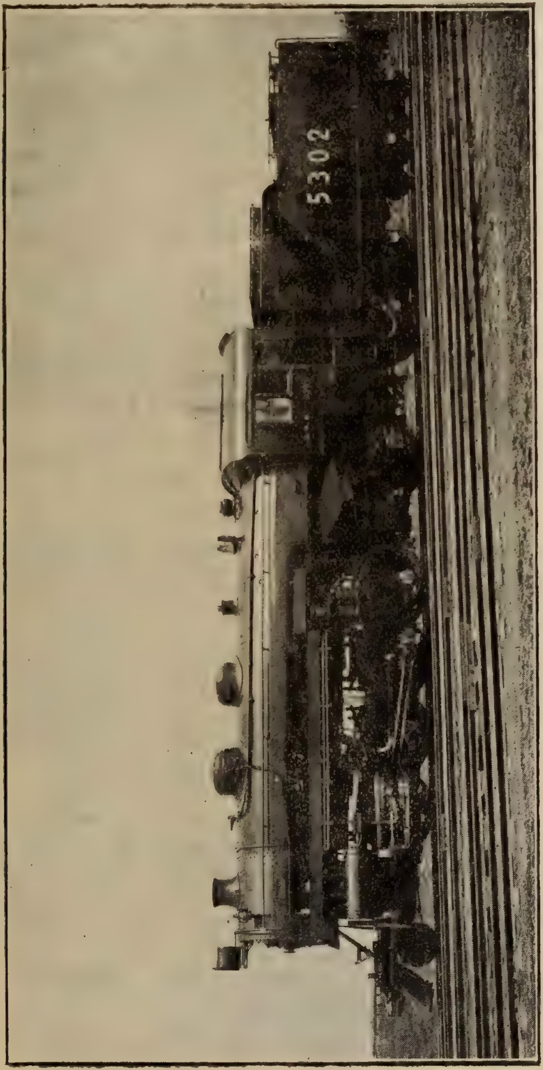


Fig. 10.

From 1908 to 1921, three things have remained constant for all C.P.R. locomotives working on the Rocky Mountain section, namely:

(1) The driving wheels have all been 4ft. 10in. diameter.
(2) The Boiler Pressure has been 200 lbs. per sq. inch.
(3) All engines have been superheated.

The tractive effort has however progressively increased from 36,200 lbs to 65,870 lbs. (or 80 per cent.), while cylinders have grown from 21in. diameter by 28in. stroke to 26½in. diameter by 32in. stroke or an 81 per cent. increase in volume. These figures are an eloquent tribute to the progress which has been made in modern locomotive boiler design. It is now six years since I was in Canada; I fear I have given you but a meagre impression of the awe-inspiring and terrific magnificence of the Rocky Mountains, and a very inadequate appreciation of the great locomotives which the genius of the Canadian-Pacific Railway has created to conquer them.

It is a spectacle to stir the blood of any British railwayman to see the C.P.R. "Transcontinental"; all dusty in summer, or snow-coated in winter, and travel-stained after the long 3,750 mile haul across Canada from the Atlantic coast — gliding into the Vancouver terminus and coming quietly to a standstill at the very edge of the wide Pacific.

APPENDIX A.

SOME CANADIAN PACIFIC RAILWAY LOCOMOTIVES.

Date.	Type.	Boiler Pressure.	Cylinders.	Driving Wheels.	Tractive Effort at 85 per cent. Boiler Psr.	Adhesion Factor.
(A) Freight Engines for Rocky Mountain Section—(ALL SUPERHEATED).						
1908 ..	2-8-0	200lbs.	21in. x 28in.	58in.	36,200lbs.	4·65
1909 ..	0-6-6-0	do.	23¼in. & 34in. x 26in.	58in.	57,400lbs. (actual T.E.)	4·75* Malet
1917 ..	2-10-0	do.	24in. x 32in.	58in.	54,100lbs.	4·15
1919 ..	2-10-2	do.	26½in. x 32in.	58in.	65,870lbs.	4·18
(B) Mixed Traffic Locomotive (SUPERHEATED).						
1908 ..	2-8-0	180lbs.	24in. x 32in.	63in.	44,700lbs.	4·25
(C) Passenger Locomotive (SUPERHEATED).						
1920 ..	4-6-2	200lbs.	25in. x 30in.	75in.	42,600lbs.	4·25

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*THE FOLLOWING TWO EXAMPLES OF MODERN MALET COMPOUNDS NOW WORKING ON U.S.A. RAILWAYS ARE OF INTEREST:—(1) Carries a High Pressure, and (2) a Medium Pressure—

(1) ..	2-8-8-2	240lbs. Superheated	25in. and 39in. x 32in. 14in. Piston Valves	57in.	106,000lbs.	4·5
(2) ..	2-8-8-2	200lbs. Superheated	28in. and 42in. x 32in. 15in. and 17in. Piston Valves	57in.	104,000lbs.	4·4

APPENDIX B.

Locomotive Ratios—Canadian Pacific Railway.

RATIOS.	Malets. 0-6-6-0.	R-3 Class. 2-10-0	S-2 Class. 2-10-2	G-3 Class. 4-6-2
$\frac{\text{Weight on Drivers}}{\text{Tractive Effort}}$	4·57	4·16	4·18	4·26
$\frac{\text{Total Weight}}{\text{Tractive Effort}}$	4·57	4·62	5·38	7·04
$\frac{\text{Traction Effort by Diam. Drivers}}{\text{*Equivalent Heating Surface}}$	975	889	662	675
$\frac{\text{Equivalent Heating Surface}}{\text{Grate Area}}$	59	60	78	73
$\frac{\text{Firebox Heating Surface}}{\text{Equivalent Heating Surface}}$	6·47%	5·25%	6·24%	6·27%
$\frac{\text{Weight on Drivers}}{\text{Equivalent Heating Surface}}$	77	63·8	47·6	38·2
$\frac{\text{Total Weight}}{\text{Equivalent Heating Surface}}$	76·8	71	61·4	61·2
$\frac{\text{Equivalent Heating Surface}}{\text{Cylinder Volume}}$	1·78	2·10	2·83	2·77
$\frac{\text{Grate Area}}{\text{Cylinder Volume}}$	4·4	3·47	3·63	3·15
$\frac{\text{Tractive Effort}}{\text{Equivalent Heating System}}$	15.8	15·3	11·4	9·05

* Equivalent Heating Surface. = Total Evaporative Heating Surface, plus 1·5 Superheater Surface.

APPENDIX C.

FULL DETAILS OF THE THREE PRINCIPAL CLASSES OF LARGE FREIGHT LOCOMOTIVES NOW WORKING OVER THE C.P.R.

ITEM.	TYPE.		
	2-8-2 "Mikado." Fig. 10.	2-10-0 "Decapod." Fig. 8.	2-10-2 "Santa Fe'." Fig. 9.
Cylinders	25½in. x 32in.	24in. x 32in.	26½in. x 32in.
Coupled Wheels	5ft. 3in.	4ft. 10in.	4ft. 10in.
Maximum O.S. Diameter of Boiler	7ft. 6in.	—	7ft. 8in.
Working Pressure (Super heated)	200lbs.	200lbs.	200lbs.
Firebox	10ft. long x 7ft. wide	10ft. long x 7ft. 5in. wide	10ft. long x 7ft. 5in. wide
TUBES :—			
Number	211 and 40	145 and 28	219 and 43
Diameter	2¼in. and 5½in.	2¼in. and 5½in.	2¼in. and 5½in.
Length	18ft. 6in.	19ft. 1in.	20ft. 6in.
WHEELBASE :—			
Driving	16ft. 6in.	—	21ft.
Engine	35ft. 8in.	—	40ft. 3in.
Engine and Tender	68ft.	—	72ft. 10in.
WEIGHT IN WORKING ORDER :—			
On Leading Wheels	28,000lbs.	25,000lbs.	23,875lbs.
,, Coupled ditto	235,000lbs.	225,000lbs.	274,275lbs.
,, Trailing ditto	57,500lbs.	—	52,925lbs.
Engine	320,500lbs.	250,000lbs.	351,075lbs.
Tender	178,100lbs.	—	180,000lbs.
Fuel	Soft Coal or Oil	Soft Coal or Oil	Soft Coal or Oil
HEATING SURFACE :—			
Tubes	2287·66 square ft.	1630·00 square ft.	2632·28 square ft.
Flues	1060·12 ditto	770·00 ditto	1263·47 ditto
Firebox	274·00 ditto	185·00 ditto	316·50 ditto
Arch Tubes	43·00 ditto	—	43·75 ditto
Total	3664·78 square ft.	2585·00 square ft.	4256·00 square ft.
Superheater	845·00 ditto	628·00 ditto	1015·00 ditto
Grate Area	70·3 ditto	59·0 ditto	74·2 ditto
Tracture Effort at 85 per cent. B.P.	56,147lbs.	54,100lbs.	65,870lbs.
Adhesion Factor	4·18	4·18	4·18
TENDER CAPACITY :—			
Fuel	12 tons	12 tons	12 tons
Water	8,000 Imp. Galls.	8,000 Imp. Galls.	8,000 Imp. Galls.

DISCUSSION.

The CHAIRMAN said that the Author had given them a very interesting paper, the more interesting as it was the result of his own experiences, and especially in connection with the articulated locomotive, a design novel to us in this side of the water. He did not think it at all likely that we should see Malet locomotives on this side for several reasons. In the first place the turntables would put them quite out of the question, and in the second place unless we could make use of the great adhesive weight given by the Malet locomotive it would not be of much use to us. If we use a Malet it means we get at least six working axles, which adds to the adhesive weight, and to make use of it we must have larger cylinders which mean larger boilers, and in that direction we are limited by our load gauge. The Canadian and American load gauges are much more generous than ours which is now practically up to the limit, so unless we can find some way of increasing the load gauge we cannot make use of the greater adhesive weight of the Malet locomotive.

He said there was a point mentioned about the control of the side movement of the bogie: the inclined plane arrangement which is similar to that used on the G.W.R. pony trucks was supplemented by the use of two springs which acted partly as control and partly as a centring device. He would like to ask if there was any initial compression put in these springs when the pony is in its central position. The Author replied that this was so; there was sufficient initial pressure to bring the initial rolling control to the figure he had mentioned. The roller travelled flat for two inches on the central line of the boiler, and the screws were compressed so that the resulting pressure was about 1,650 lbs. Another point in comparing the Canadian with ours was the allowable weight per axle. For the Pacific type of engine, the load per axle worked out at about 25 tons, which figure was quite out of the question with us on account of the permanent way, but for the other types of engines the load per axle was in the region of 20 tons.

The AUTHOR said he did not suggest that Malet locomotives should be used in Great Britain. They could not, economically, because the only type we could use here would be a small one which could be turned on a 70ft. turntable, and small Malets produced usually excessive maintenance costs, which really went to show that for a Malet engine to pay the weights which it has to haul must be far and above that which any ordinary type can handle: such big engines as this would be impracticable in this country. Also a 2-10-0 engine can pull practically an equal weight to a Malet engine of the same weight, and with less the maintenance cost.

Mr. STANIER said that he remembered early in 1901, when the new shop was being built, that it was reckoned to be the last word in erecting shops. The late Mr. Dean designed it to deal with the largest engines he could conceive would run on English rail ways, *i.e.*, the 2600 class and the "Cities." Within six years the "Great Bear" was built, and that is still ahead of our own Engineering Department. Twenty tons per axle is the limit for modern bridges on the G.W.R., and the "Great Bear" has 20 tons on an axle. That was 15 years ago, so that in this country, although we are confined to such small engines, the Locomotive Department is generations ahead of the Engineering Department. Engine No. 4,700, one of the latest developments on the G.W.R., has 19 × 30 cylinders, and a boiler that will put say 18 or 18½ tons on each axle. That engine will be able to run on any main line. He said one is interested to see that in America they can develop a 2-10-2 with their advantages of load gauge, and the risks their Engineering Department are prepared to take. One could only take it to be risks when one remembers the trestle bridges they ran over, and a 2-10-2 with enormous boiler and cylinders cannot at any rate be a cheaper engine to run. He said the Author had not said anything of the efficiency of the engines. He had compared the efficiency ratios on some of the American and G.W.R. engines. Some years ago an American Company built an engine that was to be the last word in locomotive construction. On comparing this with the "Great Bear" ratios, we were very much ahead of the last word in American locomotive design. Could the Author tell us how the efficiency ratios of these Canadian Pacific engines compare with modern English Locomotive practice? Modern English design is as efficient as experience can make it. The American special engines are built of alloy steel parts, and the piston rods are hollow and heat treated. The connecting rods are nickel chrome and heat treated, yet the efficiencies are lower comparing the American engine with the "Great Bear." He said the G.W.R. had used a great deal of alloy steel experimentally, but the general practice was to use straight carbon steel. He would be interested to hear if the Author had any information to give as to whether alloy steel was found advantageous in these big engines.

Replying to Mr. Stanier, the AUTHOR said there were now no wooden bridges on the Canadian Pacific Railway. When the first urgent demands came for increased power on the Rocky Mountain section, there were, and that was one reason why the weights had to be kept down. Then the engines had to keep to 19 to 20 tons per axle (similar to over here), including the 0-6-6-0 Malet described. The trestles have all since been replaced by Steel structures, and the Engineering Department now allows large engines to run carrying about 25 tons per axle. With regard to the latter part of Mr. Stanier's inquiry, he could not say very much as it was six years since he was in Canada. Many of the figures he had given in the paper were sent to him by the Chief Mechanical Engineer of the C.P.R., and they were not sufficient to work out all the efficiencies. He did not think the vast distances of the North American Continent were appreciated when discussing English and American railway practice. The main thing over there is to get the trains along over immensely long sections. Railways were laid very cheaply in the first instance because they had to get an enormous country developed, and frequently the townships would spring up almost alongside the laying of the track. The speeds run over there are not generally so high as on this side—such high speeds are not needed, because people do not expect to do business in two or more large cities in the same day as in England. He said the Chief Mechanical Engineer of the C.P.R. had kindly said that if the data sent was not sufficient he would be very pleased to supply additional data. The Author would write and ask for the complete efficiency ratios. He said that when they built the Malet the C.P.R. certainly did use alloy steel, but could not say what their 1921 practice was in this particular respect.

Mr. E. J. F. PLAISTER raised a question regarding flangeless tyres and the arrangements for a long locomotive like the one described.

The AUTHOR replied that he had recently obtained some information from the Baldwin Locomotive Company about modern types of Malet Engines, and on these very long engines the designers usually leave off the flanges on a middle pair of wheels, but whether the Canadian Pacific do this on their 2-10-2 engines he could not say. He did not think there was much difficulty in getting a 10 wheel-coupled engine to curve easily. They are low speed engines, and they have a traversing pony truck in front and one at the rear. The speed they run is largely from 7 to 20 miles per hour, so there is nothing very dreadful, even in running round the sharp curves mentioned in the paper. One thing about Malet engines is that there is obviously a point where a curve joins a straight, or runs from the straight, at which the articulated pin would be on the junction of the tangents of the curve, and this is the point of danger as the two trucks tend to separate, and the articulated pin has a snatch. The effective rigid wheel base, as far as the front truck of the 0-6-6-0 Malet is concerned, is practically the distance between the rear flange of the front truck and the rear truck. The front truck guides from the articulated pin and not from the rear flange of the truck. In the centring arrangement on Malet engines great care is taken to ensure that there may be a definite pull on the boiler through the medium of the front truck, the action of which on entering a curve was similar to that of an 0-6-0 tank engine. He could not say the thickness of the flanges through the 2-10-2 engines.

Mr. Hinton referred to the system of lubrication used on these locomotives, and said one was almost inclined to think there would be some trouble through the oil congealing owing to the low temperature. It was also mentioned in the paper that the pull-out regulator was standard practice. Exactly what advantage had that? He would also like to have some details of the equalising pipes between the boiler proper and the feed water section. In the paper it was also mentioned that a very gentle blast was obtained. Did this do away with any need of a regulator on the blast pipe, such as a "jumper ring," which is standard G.W.R. practice?

Replying to Mr. Hinton, the Author said that with regard to lubrication, so far as he knew, the C.P.R. used mechanical lubricators, generally speaking, and on the Rocky Mountain section he believed a lubricator somewhat similar to Mr. John Robinson's "Intensifore" was utilised, which kept the oil fluid in the cold atmosphere. He did not know whether there was any trouble through the congealing of the oil, but had no doubt but that the best system was the G.W.R. one, where the oil was fed into the steam pipe. With regard to the pull-out regulator, he said this was largely a matter of taste. A number of English locomotive engineers and an equal number of Americans would probably argue the whole evening on the subject and never get anywhere, but American and Canadian enginemen are accustomed to the use of a pull out throttle. With regard to the equaliser pipes, he said these were 4in. internal diameter; they were seated into saddles, riveted to the boiler shell, the seatings were conical, and the pipes held in place by bolts. He said these outside pipes might appear to be terrible things but no trouble was experienced with them. He said he remembered in 1906 Mr. Churchward reading a paper on large locomotive boilers before the Institute of Mechanical Engineers, in which he described some experiments made to ascertain the direction of water circulation, and which indicated that the water tended to travel from the front towards the fire-box. Mr. Churchward then suggested that it might probably be beneficial to the circulation if outside circulating pipes were fitted, and that such outside tubes had been used in France and America. With regard to the blast pipe, the Author thought somebody would say that 4¾in. seemed a small orifice for so large an engine. In comparing it with British and G.W. practice it does seem small, but it has to be realised that the 7in. pipe leading from the L.P. cylinders to the blast pipe was a very long pipe and acted as a reservoir: the back pressure on the L.P. cylinders was small. There was no regulator on the blast pipe orifice, which was satisfactorily maintained at 4¾in. right through the experiments.

Mr. Cook asked if the tests mentioned with the Malet taking 700 tons were, as he presumed, single-handed or with a second engine in front, as it seemed an enormous strain on the couplings in view of the gradient. About what size was the coupling used? Also a question with regard to the fuel used. Was it the general practice to use coal? He saw a report some time ago that oil fuel had been used to a large extent.

With regard to the weight taken of 700 tons, the Author said this was the maximum weight taken on that grade by the Malet alone, but the normal weight was 640 tons which would allow the engine to work quite easily. So far as he knew, however, the Malet was generally used as a pusher, in the rear of larger trains. The couplings used were the usual automatic couplings standard for all rolling stock in America and Canada. They were very big things, massive castings which you could not break very easily.

With regard to fuel, he said that the latest types of locomotives built by the Canadian Pacific Railway were fitted to burn coal or oil. He did not know to what extent they are now using one or the other fuel.

Mr. W. A. Stanier said that the Author had referred to coal or oil being used. He would like to know the Author's opinion about the use of pulverised coal in the Rockies. He believed it was a very usual method of firing engines. We had also heard of some experiments with it in this country, but he understood that another method of using coal or oil is being experimented with. It is generally known as Colloidal Fuel—a mixture of oil and powdered coal.

The Author replied that he could give no definite information with regard to powdered coal. All he knew of it was from a paper read by a gentlemen who advocated it, and that the G.C.R. found it a very dirty fuel to handle. As regards colloidal fuel, this was experimented with during the war, largely by the United States Committee of Submarine Defence. One of the American Torpedo Boats—the "Gem"—used it with very satisfactory results, but the war came to an end before much had been done. Its claims are these. Varying percentages of liquid fuel, not necessary oil, residuals, even tar, can be mixed with varying quantities of ground coal [not coal dust, but ground in machines somewhat similar, he believed, to those paint is ground in] and these mixtures vary from fluidity through various viscosities to a thick paste. The mixture generally used is about 40 per cent. of ground coal and 60 per cent. of oil, and this makes a mixture which will flow. Its advocates, however, prefer to put a small rotary pump in the pipe line, which pump is really a displacer, and passes the fuel on to the fire-box. The pump is driven by a small steam turbine, and the driver can regulate the supply of fuel to a nicety. The fire-box nozzles used are exactly the same as for oil fuel. The advocates of colloidal fuel recommend that no difference be made in these. The principle claim for colloidal fuel is this, that if a low grade oil and a low grade coal are taken the resulting mixture is burnt with as complete combustion as oil fuel alone. However perfectly a fire-box may be designed a great number of potential B.T.U. from coal will go up the chimney. Combustion with straight oil fuel is far more complete, but oil is expensive. With colloidal fuel it is claimed that the combustion is equally good to that of straight oil, but that the cost per ton of the colloidal mixture is much less than that of oil alone; in other words, that colloidal fuel will give an equivalent or higher fire-box temperature per unit weight of fuel than with coal alone, at a cost, per heat unit absorbed, of less than that of either straight coal or straight oil.

Mr. Cuss asked how the colloidal fuel was conveyed to the fire-box, and whether or not an ordinary coal-burning locomotive with an ordinary brick arch is suited for that purpose also for oil fuel, so that one fire-box constructed for one fuel would be suitable for liquid or solid fuel. Also when 2-10-2 locomotives are derailed, does it occupy the main lines for very long before they are on again, or have they special high-speed arrangements for replacing them at short notice? Another point, what arrangements are made for removing ashes and clinkers and cleaning the boiler tubes, and what arrangements have they whilst taking water to the boilers from the tenders to protect against the severe frosts.

Replying to Mr. Cuss, the Author said that he thought it was impossible to burn three kinds of fuel efficiently in one box. The advocates of oil burning usually arrange that the fire-box shall be lined with fire-brick. The claim is that a locomotive fitted for oil can burn colloidal fuel without alteration. With regard to the displacement pump, the colloidal fuel comes down from the tender, passes under the fire-box and up about 10 inches under the boiler, feeding into the front of the fire-box. This flow is by gravity (assisted by the displacer pump), and the flame is towards the back of the fire-box. The jet advocated for colloidal fuel is not exactly a nozzle, but the fuel trickles out of a rectangular slot at the end, where it is met by the usual arrangement of steam jet and so carried into the fire-box. With regard to cleaning boiler tubes, the C.P. Railway used to employ one of the common flexible arrangements. As regards clearing the ashes and cinders the arrangement was no different for the big engines than for the small ones.

Speaking of derailments, the Author said he had never been in one on the C.P.R., but all engines carry re-railing ramps and can often pull themselves on to the rails again. There was no peculiar difficulty with big engines that he knew of.

Mr. W. A. STANIER said that a little time ago he was talking to two American engineers. They said with regard to the derailment of a large Malet engine that it was quite simple. You put down the re-railing ramps, and the engines work themselves up them. The track out there is different to ours here. They can get a re-railing ramp that will work. It is difficult to get a re-railing ramp to fit a chaired road. He said they had experimented with many, but have never found one that is entirely satisfactory. It is difficult to get a ramp that will keep near the rail when the engine is going up. In the States they use re-railing ramps, and sometimes large steam winches. It is a more simple matter to deal with derailments than in this country unless the engine overturns.

Mr. MANNING asked if there was any reason for not attempting a higher boiler pressure than 200, also what type of injectors were used?

The AUTHOR said that at the beginning of this century the C.P.R. started out with 200 lbs, and since then it has been standard. He said he believed that Mr. H. H. Vaughan, who was superintendent of motive power till about 1915, saw a long way ahead of most other railways of the world with regard to superheating. Quoting a paper read before the Institute of Mechanical Engineers in the early years of this century, Mr. Vaughan had contributed some remarks to the discussion, saying that even then for some years every engine on the C.P.R. had been superheated, even the smaller ones. He started with a pressure of 200lb., and his successor has carried it on. There is no load gauge restriction for large cylinders, so the lower pressure can give all the power required. He did not know why they had not used a higher pressure. He said there had recently been articles in the "Railway Gazette" and elsewhere about a large 2-10-0 engine for the Great Indian Peninsula Railway. That engine was given the low pressure of 160 lbs. per square inch, and to develop the tractive effort necessary the designer had to resort to four cylinders, and correspondingly higher maintenance. It seemed to him that that was the way *not* to do things. He did not know if any of them there know why they have such low boiler pressure in India. The G.I.P. engine referred to has four cylinders 20in. x 26in. stroke, and the tractive effort produced with 160 lbs. boiler pressure is 53,000 lbs., the engine being built to full load gauge dimensions. If the minimum load gauge did not permit of two sufficiently large cylinders with this low pressure, to produce tractive effort aimed at, why not have raised the boiler pressure slightly? Had the boiler pressure been made the moderate one of even 200 lbs. per square inch two cylinders 23in. x 32 stroke would have given an even higher tractive effort. After all 75 per cent. or more of the freight haulage of the world was being done by two-cylindered locomotives.

The CHAIRMAN said that going in for four cylinders seemed to be a step in the right direction. The weight of the reciprocating parts for each cylinder is much smaller, and those parts balance in themselves, and so reduce the hammer blow on the rail, which in the case of a large two-cylinder engine is appreciably disturbing.

Mr. STANIER said it was largely a question of the speed the engine had to work at. If you have a big enough load gauge a 2-10-0 with 4ft. 8in. wheels and two cylinders would never reach beyond 25 miles per hour, and the hammer blow is kept within limits. With regard to the low boiler pressure on the Indian Raiways he said that in India they depended largely on native labour for maintaining the boilers, and they are afraid to risk putting native labour, which requires a large amount of supervision, on high pressure boilers above 160 lbs.

Mr. KERRY bore out Mr. Stanier's remarks regarding native labour in India. In Calcutta they had continual trouble with leaky stays due to the bad work put in by native workmen. You cannot depend on the work they do unless they are continuously supervised, and he said he thought the Author would find that that was the real reason of the low pressure boilers.

In closing the discussion the CHAIRMAN said the paper would be a useful addition to the Society's proceedings, and they would be glad to avail themselves of the Author's offer to obtain the efficiency figures, to be bound up with the Transactions.